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Working Paper

The Impact of Regulation and Competition on the Adoption of Fiber-based Broadband Services: Recent Evidence from the European Union Member States

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Next generation telecommunications networks, regulation, competition, adoption

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Abstract

Although fibre-deployment of next generation access (NGA) broadband networks is considered as a decisive development for any information-based society, investment activities and especially the adoption of fiber-based broadband services take place only very gradually in most countries. This work identifies the most important determinants of NGA broadband adoption, using most recent panel data from the European Union member states (EU27) for the years from 2004 to 2012.

The results show that stricter previous broadband access regulation has a negative impact on NGA adoption, while competitive pressure from mobile networks affects NGA adoption in a non-linear manner. It appears that the approach of strict cost-based access regulation embedded in the EU regulatory framework is at odds with the ambitious targets outlined in the European Commission´s “Digital Agenda”. Finally, we find strong evidence for network effects underlying the NGA adoption process.

1 Introduction

The traditional ("first generation" copper or coax-based) broadband networks appear to be outdated and it has become necessary to speed up these networks in recent years to account for the growing demand for bandwidth and connection speed. According to "Nielsen´s law", broadband connection speed increases every year by 50% (FTTH Council Europe, 2012, p. 12). Next generation fiber-based access (NGA) networks deployed in the ground provide almost unlimited bandwidth capacity at the highest possible speed. As these networks also represent a general purpose technology they are expected to induce significant productivity improvements and growth across major economic sectors such as health, electricity or transport (e.g. Czernich et al, 2011). However, substituting the traditional infrastructure by fiber optic networks also involves massive investment volumes.[1]

Demand in terms of adoption (penetration) and supply-side activities in terms of investment in fibre-based network infrastructure (coverage) vary significantly in international comparison. Most European countries are lagging far behind leading Asian fiber nations (such as Japan, Korea, Taiwan or Hongkong), but also behind the development in the US (Briglauer and Gugler, 2012). As regards NGA adoption within Europe, Northern and Eastern European economies are leading by a large margin with NGA household adoption levels between ~10% (Denmark and Latvia) and ~26% (Lithuania) at the end of 2011. Exceptional cases are Belgium and Luxembourg where focus on less expensive NGA deployment technologies facilitated adoption levels of ~45% and ~85%, respectively. However, most of the other European countries still show NGA adoption levels (far) below 5%, including all major Western and Southern European economies.[2]

Europe´s gap in NGA deployment was recognized by the European Commission (EC) and explicitly addressed in its "Digital Agenda", which specifies quite ambitious goals in terms of high-speed broadband coverage and penetration.[3] In achieving these goals one of the most controversial regulatory issues in Europe (and elsewhere) is whether emerging NGA infrastructure should be subjected to sector-specific ex ante access regulation. Former – mostly state-owned – telecommunications monopolists ("incumbents") argue that sector-specific ex ante regulation restricts their ability to generate future revenues. Accordingly, fibre roll-out could only, if at all, be done on the

1 Total investments for a nationwide NGA deployment (coverage) depend inter alia on the network topology employed and the targeted coverage levels and add up to billions of euros (wik consult, 2008).

2 See Figure A.1 in the Annex which reports time series plots for high and low cost NGA deployment scenarios for the EU27 countries.

3 The Digital Agenda "seeks to ensure that, by 2020, (i) all Europeans have access to much higher internet speeds of above 30 Mbps and (ii) 50% or more of European households subscribe to internet connections above 100 Mbps" (European Commission, 2010a, p. 19). Whereas the target in (i) refers to a coverage level of 100%, the target in (ii) is related to a minimum household adoption level subject to quality characteristics that can be realized with NGA technolgies only.

basis of deregulation of relevant markets; at least a temporary removal of ex ante obligations ("regulatory holidays") is deemed to be essential. Regulation of network access would, in turn, be detrimental to dynamic efficiency in terms of investment incentives and infrastructure innovation. Instead, it would be sufficient to rely on market mechanisms and infrastructure-based competition in particular. Conversely, alternative operators who are dependent on access regulation ("service-based entrants") as well as some national regulatory authorities (NRAs) fear the rise of NGA networks as another upcoming monopolistic infrastructure, if regulation is released or removed entirely. They argue that incumbent firms or other alternative NGA infrastructure operators would gain an essential and long-lasting competitive ("first-mover") advantage, which implies the need to have appropriate ex ante regulation in place. Regulatory-induced service-based competition would also have an immediate effect on static efficiency in terms of lower prices and hence on adoption of (new) communications technologies on the demand side.

Based on an unbalanced panel of the EU27 member states during the period of 2004 to 2012, this paper addresses the following research questions: (i) What is the impact of broadband access regulations on NGA adoption? (ii) How does infrastructure-based competition stemming from wireless (mobile) networks influence the extent of NGA adoption? Finally, (iii) the paper examines the role of network effects which might lead to an endogenous adoption process. This paper represents the first European-based attempt to quantify the determinants of NGA adoption with most recent country-level data. Multiplicity of methods as well as a broad set of control variables serve as important robustness checks. Furthermore, we argue that there is no endogeneity problem in terms of reverse causality in our empirical specification, as we assess the impact of demand and supply-side determinants that are related to first generation broadband services on second generation NGA markets and services.

The remainder of the paper is organised as follows: First, we review the related empirical literature in section 2. Section 3 briefly provides necessary background information on the technical context of NGA networks. Section 4 then describes basic hypotheses concerning the role of sector-specific regulation and competition as well as other main cost and demand factors. Section 5 describes our dataset. Section 6 presents the empirical specification and most relevant econometric issues. Section 7 discusses the main empirical results. Section 8 summarises and contains some final remarks.

2 Literature review

Empirical literature related to the impact of broadband access regulations and competition can be divided into three broad categories: (i) quantitative analysis focusing on the impact on investment (ii) quantitative analysis focusing on the impact on adoption (penetration) and (iii) qualitative analysis with focus on penetration or investment. The latter appears to be most meritorious in case of too few observations where quantitative analysis cannot provide reliable guidance. However, we think that availability of NGA related data is sufficient now to allow robust statistical analysis. Accordingly, in this section we focus on quantitative studies only and do not review the literature related to qualitative studies.[4] In reviewing the quantitative literature one has to be aware of the heavily interest-driven nature of the discussion and that a large number of contributions represent directly industry-sponsored work. This seems to be especially relevant for econometrics work due to its high sensitivity to the methodological specifications and "the opacity of its techniques to the vast majority of policy makers" (Berkman Center, 2010, p. 96). Therefore, our literature review also excludes industry-sponsored work which has not been published in peer-reviewed academic journals.

Regarding the impact of regulation on investment ((i)) Jung et al. (2008), who use US data for the years from 1997 to 2002, find that infrastructure competition increases investment incentives while mandatory access obligations at best, have a weak effect on investment of infrastructure operators. Recent work with data from EU countries exhibits similar results: Grajek and Röller (2011) investigate the relationship between regulation and total investment in the telecommunications industry. Their study is among the few which explicitly account for the endogeneity problem of regulation and investment. Investment is quantified therein rather broadly by the tangible fixed assets of telecommunications operators and, thus, does not explicitly refer to broadband or NGA deployment. Wallsten and Hausladen (2009) are the first to estimate the effects of broadband access regulation on NGA deployment. They find that countries where broadband access regulation is more effective experience lower fiber deployment. However, they use data for the years from 2002 to 2007, which only covers the NGA roll-out at the very early stage and the authors do not capture the investment dynamics. Briglauer et al. (2013) investigate the determinants of NGA investment with a direct measure of real NGA investment for yearly data from 2005 to 2011. They find that stricter previous broadband access regulation has a negative impact on NGA deployment, while competitive pressure from cable and mobile networks affects NGA deployment in a non-linear manner.

Regarding the literature on the impact of regulation on adoption ((ii)) there are several contributions related to broadband markets, but actually no NGA related studies: Using US data from 2001 to 2004, Denni and Gruber (2007) find that infrastructure-based competition has a positive impact on broadband diffusion in the longer term, whereas regulatory-induced service-based competition has a positive impact only if the number of service-based entrants is not too large. Non-US based work mainly refers to OECD country level data: Bouckaert et al. (2010) examine the determinants of broadband penetration for the years from 2003 to 2008. They find that infrastructure-based (inter-platform) competition has a positive impact on broadband penetration, whereas service-based (intra-platform) competition is an impediment to penetration. Lee et al. (2011) analyze determinants of broadband diffusion for the years from 2000 to 2008. With respect to unbundling obligations, the authors find a positive and significant effect on the speed of diffusion. They admit, however, that

[4] A comprehensive overview on qualitative studies can be found in Berkman Center (2010, pp. 121-136). Our review also excludes a number of recent quantitative studies where data are based on surveys (e.g. Sunada et al., 2011) and which do not consider inter alia the role of regulation and competition.

unbundling might have a negative impact on long-term investment and the broadband saturation level. Cava-Ferreruela and Alabau-Munoz (2006) find that inter-platform competition has a significant and positive impact on broadband penetration whereas unbundling has no significant effect for data from 2000 to 2002. Finally, some contributions refer to data from European countries: Distaso et al. (2006) analyze EU related data from 2001 to 2004 and find that inter-platform competition is the main driver of broadband take-up and has a more important role for penetration than service-based competition, especially in the longer term. Höffler (2007) examines data for sixteen Western European countries for the years from 2000 to 2004. He concludes that broadband deployment was predominantly triggered by infrastructure-based competition with service-based competition playing a secondary role.

Summarizing, the majority of the empirical literature suggests that infrastructure-based (inter-platform) competition has a positive impact on both investment and penetration. In turn, the evidence on service-based competition relying on broadband access regulations tends to be negatively related with investment activities, while the impact on broadband adoption seems to be less clear. To the best of the author´s knowledge there is no empirical work that employs a direct measure of NGA adoption and examines the causal impact of regulation and competition. This paper intends to fill this gap.

3 Relevant NGA scenarios

Historically, first generation legacy networks[5] deployed twisted copper-wire pairs to overcome the last mile (“local loop”) to the subscriber in order to provide narrow bandwidth voice telephony services (POTS/ISDN) only. Many decades later, they were made capable of supporting broadband services by means of Digital Subscriber Line (DSL) transmission technology. However, due to technical reasons, bandwidth of DSL technologies is limited. In order to realise NGA characteristic bandwidth, it is necessary to shorten the length of the copper-based local loops by placing the DSL transmission equipment closer to the retail customers’ premises, e.g. in the cabinets which house distribution frames (“fibre to the cabinet” - FTTC). In the remaining copper-wire line of the last mile the latest DSL transmission technology is used. This solution can provide bandwidths of 20 Mbit/s to 100 Mbit/s. In addition to upgrading first generation copper-wire (DSL) networks in the local loop, the roll-out of high-speed communications networks might also be realised by upgrading cable (coax) television networks which is referred to as Fibre-to-the-last-amplifer. The latest cable transmission technology already allowed for bandwidths up to 150 Mbit/s.

Similar or even higher bandwidths (above 100/150 Mbit/s) can be achieved if optical fibre is extended to or into the building (“fibre to the building” - FTTB). Only the remaining wiring inside the building relies on conventional copper-wires. If the optical line is directly connected to the individual home

5 This term refers to networks already in existence and historically owned exclusively by incumbent operators.

("fibre to the home" - FTTH), this would be the most future-proof technological solution, as it enables a large number of future services with nearly unlimited bandwidth (RTR, 2010, pp. 189-191).[6]

FTTx stands for a family of technologies that include all the NGA scenarios described above. As such it differs from a more narrow definition that refers to cost intensive FTTH/B technologies only where fiber infrastructure terminates inside or no more than two meters away from the consumers' building, either to the basement, the house or the apartment.[7]

During the relevant period of our analysis (2004 to 2012) mobile broadband access has already been facilitated by 3G+ technologies such as GPRS, EDGE, UMTS und HSDPA. Moreover, the industry expects Long Term Evolution (LTE) to enable transmission rates similar to wireline NGA (FTTx) scenarios in the near future. Currently, however, LTE is still in the test phase and the before-mentioned mobile broadband standards are far from achieving FTTx specific bandwidth levels. Therefore, mobile broadband is not considered as a relevant (second generation) NGA technology in this analysis.

4 Hypotheses

From the empirical literature one can infer that there is a common understanding that both, demand-side and supply-side factors have an influence on the adoption of fibre-based broadband services. Although the drivers of demand differ from supply drivers, most studies implicitly refer to a direct and positive relationship between investment (coverage) and adoption (penetration). Clearly, network coverage is a pre-condition for successful adoption of NGA services and therefore the higher the available infrastructure stock, the higher the potential subscriber base (Bouckaert et al., 2010; Wallsten and Hausladen, 2009).[8] This section identifies determinants of NGA investment and adoption and sets out corresponding hypotheses, which are aligned to the underlying research questions. Section 4.1 and 4.2 focus on regulation and competition as main explanatory variables which directly impact the supply side, i.e. NGA investment. Likewise, cost conditions will shift the supply curve but also exert an indirect impact on NGA adoption (section 4.3). Finally, the adoption process will be directly influenced by diverse demand-side factors and network effects (section 4.4). But, demand will be also related to regulation and competition which affect prices and quality and thus indirectly the adoption of NGA services.

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[6] Full definitions of terms are also available at: http://s.ftthcouncil.org/files/FTTH-Definitions-Revision_January_2009_0.pdf.

[7] Because the length of FTTH/B lines is longer compared to other FTTx technologies and thus services a much smaller customer base in the last section, the average investment per FTTH/B connection is disproportionately higher (wik consult, 2008).

[8] In our panel dataset Pearson´s bivariate correlation coefficients for FTTx coverage and FTTx adoption are 0.7014 and 0.6982 in terms of connections per household and per capita, respectively.

4.1 Regulation

In EU member states, where asymmetric ex ante regulation is imposed on first generation broadband markets, alternative operators can rent the local loop from the incumbent operator based on cost-oriented access charges ("unbundling"). This allows alternative operators to provide (first of all) broadband services. Alternative operators may also offer retail broadband services by purchasing "bitstream" as a wholesale service from the incumbent operator but at a more service-based level of the value chain. Finally, wholesale broadband access via simple resale services means that access-seeking operators receive and resell a wholesale input of the incumbent operator without any scope of technological product differentiation (RTR, 2010, pp. 176, 179).

Specific forms of NGA regulation will be defined and imposed by NRA´s only in future decisions or, if already implemented, the effectiveness of these decisions remains to be seen (Cullen International, 2011, Tables 4, 9 and 10). We argue, however, that past regulation in first generation broadband markets has clearly shaped expectations for NGA regulations. This has been recently confirmed in NGA relevant recommendations of the EC as well as in previous court decisions.[9]

On the one hand, stricter wholesale access regulations increase service-based competition at the retail level in terms of better services and lower broadband prices which exerts a positive impact on the demand side. On the other hand, tight regulation of existing broadband access products will, as mentioned above, most likely create corresponding expectations about future regulation of NGA access products which decrease investment incentives of (potential) infrastructure operators for the following: (i) imposing cost-oriented access prices for bottleneck inputs will typically reduce profits or preclude excess profits of the regulated firm, which results in an asymmetric distribution of expected profits and, therefore, in a lower net present value of investment projects (Valetti, 2003). Furthermore, access regulation typically ignores (ii) opportunity costs of real options (Guthrie, 2009) and that (iii) risks were distributed asymmetrically among regulated incumbent and entrant operators. Therefore, (iv), regulation not only reduces investment incentives of regulated infrastructure operators but also of potential entrant infrastructure operators who benefit from a risk-free option due to mandatory access obligations asymmetrically imposed on the incumbent operator (Pindyck, 2007). Finally, pending decisions on NGA regulations have already led to substantial regulatory uncertainty which constitutes another investment impediment. According to Nitsche and Wiethaus (2011), who model the effects of different regulatory regimes on NGA investment, a regime of less intense access regulations or

9 The NGA recommendation of the European Commission (2010b) as well as former draft versions clearly indicate that the EC is very much determined to extend its cost-based regulatory approach to emerging NGA communications infrastructure. The reader is also referred to the earlier decision of the German government to exempt the incumbent operator (Deutsche Telekom) from wholesale access obligations to its new infrastructure (VDSL) network ("regulatory holidays"). The EC, however, took Germany to court over this legal provision in 2007, which finally decided against it in 2009 (C-424/07).

regulatory holidays would have the most positive effects on investment, whereas the current EU standard of strict cost-based access regulation turns out to be inferior.[10]

Summarizing, we expect that ex ante sector-specific regulation in the form of mandatory access regimes has a negative impact on NGA investment and hence indirectly also on adoption of NGA services. Higher levels of regulatory induced service-based competition, however, also lower prices and enhance better services which increases demand and NGA adoption.

4.2 Competition

Telecommunications, by all means, has become one of the most dynamic and competitive industries since the beginning of the EU liberalization process in 1997/98. Likewise, recent and future investment in NGA is driven by inter-platform competition, most notably, from mobile networks, which ”threaten” first generation (copper and cable) networks and services. The so-called phenomenon of fixed-to-mobile substitution has been already quite intense with respect to narrowband voice telephony services at the beginning of NGA deployment (around 2005) and has become increasingly important until now, not only regarding voice telephony but also more and more broadband services.[11]

With respect to the potential impact of inter-platform competition on NGA investment, one has to distinguish the following opposed effects (Aghion et al., 2005): On the one hand, competitive markets bear incentives for innovative investment in view of temporary market power rents that can be captured (“escape competition effect”) which leads to a positive relation between inter-platform competition and NGA investment. Indeed, the deployment of NGA networks can be seen as the “last chance” for traditional wireline infrastructure operators to successfully escape broadband competition stemming from mobile networks with innovative and high-bandwidth demanding NGA services which cannot be realized by means of mobile broadband technologies in the foreseeable future. On the other hand, intense inter-platform competition in terms of pronounced fixed-to-mobile substitution will eventually reduce potential rents and, thus, increasingly counteract NGA investment because operators are no longer able to appropriate necessary profits from NGA investment (“Schumpeterian” effect).

Finally, one has to consider the “replacement effect” (Arrow, 1962), according to which new NGA investment would “cannibalise” quasi-monopolistic profits from old first generation (legacy and coax-

10 See also Briglauer and Gugler (2012) who evaluate NGA deployments in different geographical areas (Asia, EU and US) in view of the underlying regulatory approaches with a particular focus on the investment incentives of the current EU regulatory framework.

11 According to the EC’s “Indicators on the electronic communications market” the average EU mobile broadband penetration of all users (PC’s/Laptops and handheld devices) is about 41%, whereas fixed broadband penetration for the EU average is 27.7% (including basic and high speed connections) as of January 2012. Regarding the number of subscribers, fixed-to-mobile substitution is even more pronounced: Whereas the average EU number of mobile subscribers increased constantly up to 127% by the end of 2011, the average number of fixed-line connections decreased significantly in recent years. All data is available at the EC’s Digital Agenda Scoreboard website: http://ec.europa.eu/digital-agenda/en/scoreboard.

based) broadband services which increases opportunity costs and thus reduces the incentive to invest.[12] The replacement effect appears to be of practical relevance, as most EU27 member states have well established first generation infrastructure in view of both network coverage and recent and foreseeable advances in DSL technology standards. As a result conventional broadband services enjoy broad consumer acceptance in most EU member states which also establishes some non-negligible switching costs on consumers´ side and hinders migration to the new technology unless its incremental benefits are large and transparent enough for consumers (Grajek and Kretschmer, 2009, p. 241).

Summarizing, we expect a non-linear relationship between NGA investment and the intensity of infrastructure-based competition from mobile networks. At the same time an increase in competitive intensity has – in the same manner as regulatory-induced service-based competition – a positive impact on adoption of NGA services, i.e. on the demand side, as infrastructure-based competition will enhance better services and reduce the average broadband price level. With respect to the replacement effect, we expect that a higher diffusion of first generation broadband connections leads to a lower adoption of second generation NGA services.

4.3 Cost factors

Civil engineering and construction costs related to digging represent by far the most relevant cost drivers for NGA deployment. As these cost factors are largely fixed and sunk costs, one can expect that average deployment costs will decrease with the number of broadband/NGA subscribers ("economies of density"; wik, 2008). Furthermore, these deployment costs will crucially depend on largely time-invariant topographic and demographic characteristics such as urbanization, population or household density and housing structure, particularly the number of multi-dwelling-units, is a major issue (FTTH Council Europe, 2012, pp. 24-25).

Relevant institutional factors such as regulations on capital costs, rights of way and digging or other allowances and technical standards, local availability of ducts and dark fiber or NGA specific state aid policies also show hardly any variation with respect to the relevant time frame of our analysis.

4.4 Demand factors

Demand and willingness to pay depend on the average price for high-speed broadband services, the overall market size in terms of total communications expenditure and consumer wealth in general. Consumers with higher average communications expenditures can be regarded as being more affine with information and communications technologies (ICT) which might result in higher NGA penetration rates (FTTH Council Europe, 2012, p. 42). Demand for NGA services will also be driven by a variety of consumer and quality characteristics. Regarding the latter, which refer to performance

[12] See Bourreau et al. (2010) for a more general description of the replacement effect in the communications industry.

parameters such as latency, jitter and speed, it is typically difficult to obtain consistent data. Consumer characteristics refer to the overall affinity to ICT, conventional internet usage and usage intensity of high-speed broadband services as well as average education levels. Higher levels of education will improve e-literacy skills which are required for NGA technologies. Also, higher educated people tend to be more prone to adopt and experiment with new ICT (Kiiski and Pohjola, 2002, p. 302).

Finally, one has to consider network effects as a special type of externality underlying the NGA adoption process, in case that the number of subscribers (and/or producers) has an impact on the consumers´ utility (firms` profit) (Shy, 2010). In general, increases in adoption rates also lead to increases in usage intensity of the respective services (Grajek and Kretschmer, 2009, p. 240). Consumers´ utility can be either directly related to the possibility of communicating with one another at the consumer level, e.g. via different "Web 2.0" platforms, or indirectly, in case network effects occur at different producer levels: For instance, the more users subscribe to (high-speed) internet services, the more specific content and related applications will be programmed, which increases the consumers´ utility and willingness to adopt such (NGA) services. The same is true for the development of related hardware and electronic equipment. Furthermore, it is likely that the NGA adoption process is subject to learning spillovers, inasmuch as the value added of NGA services appears to be a priori unknown to potential consumers whose valuation will inter alia depend on the information gathered by the already existing subscriber base (Grajek, 2010, p. 133). Operators simply benefit from network size, since an increase in the total number of subscribers lowers average costs significantly in view of the NGA network topology and thus increases profits.

All network effects described above give rise to a self-propelling endogenous growth process which suggests that contemporaneous and previous NGA adoption rates are positively related leading to a virtuous circle: the higher the existing subscriber base, the higher potential network benefits.

5 Data and variables

The empirical specification is based on the following data sources: The "EU Progress Report" provides yearly data for all relevant wholesale broadband access regulations. Our second main source is the database of FTTH Council Europe which includes annual numbers of connected NGA lines for all EU27 member states. EUROSTAT / COCOM provide data on total population, education, internet usage and ICT labour costs as well as housing structure. We use the International Telecommunications Union (ITU) data to measure inter-platform mobile competition and Quantum-Web tariff data for a representative measure of the average broadband price that is related to first generation infrastructure. Finally, data from the World Bank provide us with GDP per capita, the European Intelligence Unit (EIU) with measures of labour and wage costs and the percentage of people living in urban areas and EUROMONITOR with telecommunications revenues, the number of households and internet users.

As data availability varies by variable, we use an unbalanced panel dataset of EU27 countries for the time range from 2004 to 2011 for yearly data on our independent variables and from 2005 to 2012 for yearly data on our dependent variable. All variable definitions and sources as well as summary statistics are listed in detail in the Annex in Tables A.1 and A.2, respectively.

5.1 Dependent variable

The dependent variable, *FTTx_hh*, measures adoption in terms of the actual number of households connected by relevant FTTx technologies:[13] In line with the description in section 3, this includes FTTH/B/C and Fibre to the last amplifier. The dependent variable thus represents the number of households exhibiting a sufficient willingness to pay and actively using one of the FTTx-based NGA services under a commercial contract ("homes connected").

5.2 Independent variables

The independent variables can be divided into the following categories: (i) regulation, (ii) infrastructure-based competition, (iii) prices and (iv) cost and demand controls.

5.2.1 Regulation

The regulation variable, *reg_bb,* measures the lines actively used by service-based competitors as the share of total regulated wholesale broadband lines (including unbundling, bitstream and resale) related to total retail broadband lines. Therefore, this variable not only includes all wholesale broadband access regulations as outlined in section 4.1, but it also provides a direct measure of their effectiveness.[14]

Furthermore, as outlined in section 4.1, it can be argued that the effectiveness of regulation of the "old" network infrastructure, *reg_bb,* is exogenous with respect to the deployment of "new"

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13 The other metric commonly used is homes connected in per capita terms. Both measures have each their strengths and weaknesses. Adoption in per capita terms refers to both, business and residential users, whereas household penetration omits business customers. However, household subscription data seems to be the more correct measure as fixed-wireline (NGA) connections are typically related to a single household but not to an individual subscriber (as is the case for wireless subscriptions). Hence we prefer household data, but – as it will be shown – our estimates are robust to the alternative specification in per capita terms.

14 As a consequence, we do not have to rely on broadly defined indices, dummy-based scorecards or other proxies, which are commonly used in related literature but hardly related to fixed broadband wholesale access regulations (such as the OECD regulatory index for the telecoms sector). The "Polynomics Regulation Index 2012" (Zenhäusern et al., 2012) is most related to the EU regulatory framework, but it is available only up to 2010 and captures only formal aspects of regulation but not its effectiveness. For instance, certain access regulations imposed by NRA´s might exist on paper for years without any real effect on relevant markets. In contrast, our measure incorporates the actual market effectiveness of ex ante regulations by linking these to the corresponding market outcomes (the same argument in favor of effectivity-based measures can be found in Bacache et al., 2012, or Briglauer et al. 2013). The Polynomics regulatory index 2012 is available for the years from 1997 to 2010 at: http://www.polynomics.ch/rdi.php.

infrastructure. At the same time, previous regulation on broadband markets is a rather reasonable – and in fact the best – proxy for expected NGA regulation, inasmuch as *reg_bb* represents the most related remedial measures within the EU regulatory framework for electronic communications markets.

5.2.2 Competition

The main form of inter-platform competition related to first generation infrastructure services stems from mobile networks. The variable *fms* states the share of fixed landlines to the total number of fixed landlines and mobile subscriptions and hence expresses the extent of fixed-to-mobile substitution, *fms*, in a country. Its net impact depends on the relative importance of the escape competition and Schumpeterian effect. *bb_lines_hh* measuers a country´s diffusion of first generation (copper and coax) broadband connections and services and, therefore, it directly captures the replacement effect and it is expected to negatively impact NGA adoption. *cable* measures the share of broadband cable lines whereas 1 - *cable* roughly corresponds to the share of DSL incumbent broadband lines. Both variables measure the relative importance of the main modes of intra-platform competition.

5.2.3 Prices

As outlined in sections 4.1 and 4.2, the net impact of regulation and competition on NGA adoption is undetermined, since regulatory-induced service-based competition influences prices and thus adoption on the demand side but it also negatively affects NGA investment on the supply side which decreases NGA adoption. Likewise, a high level of infrastructure-based competition brings down broadband prices but, beyond a certain level, also deteriorates NGA investment. In order to isolate the direct supply-side effects of the competition and regulation variables, one has to account for the market outcome that is related to first generation competition by controlling for the average broadband price level, *price_bb*. The net impact of the variable *price_bb* on NGA adoption is determined by the following opposing effects: (i) In case first and second generation broadband services are substitutes, an increase in *price_bb* shifts demand and increases NGA adoption. (ii) To the extent that *price_bb* stands proxy for NGA prices, an increase in *price_bb* will decrease NGA adoption alongside the demand curve. (iii) To the extent that *price_bb* stands proxy for a general broadband price level, an increase in *price_bb* will expand aggregate demand for broadband services and thus NGA adoption increases also. Finally, (iv) in case *price_bb* stands proxy for average revenue per user and willingness to pay for high-speed broadband services, an increase in *price_bb* induces additional NGA investment and thus increases NGA adoption. Since demand factors inter alia control for willingness to pay (section 5.2.5) and as we also control for the substitute infrastructure, *bb_lines_hh*,[15] we presume that the effects in (ii) and (iii) are predominant and thus expect a negative sign of *price_bb*.

[15] In case the income effect is negligible, symmetry of net substitution implies that $\partial \ln(Fttx\_hh) / \partial price\_bb = \partial bb\_lines\_hh / \partial price\_Fttx\_hh = 0$, once we control for *bb_lines_hh*.

5.2.4 Cost controls

We use the following measures for the demographic and topographic cost factors: Whereas *urban_pop* reflects different cost structures due to varying shares of rural and densely populated areas, *hh_dens* represents a country´s average household size and therefore a measure for the housing structure. The yearly number of building permissions of multiple dwelling units, *mdw*, provides another measure of household structure.

We use the following measures for NGA construction costs: Whereas *lab_cost* represents an annual labour cost index, *lab_cost_ICT* gives an annual labour cost index that is related to ICT industries and *wage* measures manufacturing costs per hour.

5.2.5 Demand controls

Total telecommunications revenues normalised to households, *telco_rev_hh*, act as a proxy for the ICT market size and, thus, for the overall willingness to pay for broadband/NGA services in a country. *GDP_pc_pp* measures income effects. Furthermore, we include the variable *iday*, which provides the share of the population that uses the internet frequently and *i_iugm*, which provides the share of population that uses bandwidth intense internet applications to cover NGA relevant consumer characteristics. The number of internet users per capita, *int_user_pc*, represents a proxy for the overall ICT affinity within a country. The educational level, *edu*, is measured as the percentage of adult population that has completed at least upper secondary education.

Finally, network effects are considered by adding the lagged dependent variable, $Fttx\_hh_{(t-1)}$, as a right-hand-side variable to the empirical specification. $Fttx\_hh_{(t-1)}$ measures the installed subscriber base and thus aggregate demand in the previous period.

6 Empirical specification

6.1 The model

As can be inferred from the literature review, some studies focus on broadband penetration, i.e. demand, while others focus on investment, i.e., supply of broadband/NGA connections. Only a few empirical studies explicitly identify broadband/NGA supply and/or demand or outline the underlying reduced form approach. Our baseline specification refers to a reduced form model where demand is expressed in terms of NGA household adoption (in logs), *ln(FTTx_hh)*. Imposing the equilibrium condition (demand = supply) eliminates the endogenous NGA related price variable and yields the following econometric reduced form specification:[16]

16 For a similar approach see Cava-Ferreruela and Alabau-Munoz (2006, p. 450-451). The authors, however, do not eliminate the endogenous price variable but pool the whole set of available demand and supply variables in their specification of broadband penetration.

$$\ln(Fttx\_hh_{it}) = \alpha_0 + \beta_1 reg\_bb_{i(t-1)} + \beta_2 fms_{i(t-1)} + \beta_3 fms^2{}_{i(t-1)} + \beta_4 bb\_lines\_hh_{i(t-1)} + \gamma' \mathbf{Z}_{i(t-1)} + \theta_i + t + \varepsilon_{it} \quad (1)$$

Equation (1) depends on the main variables of interest, i.e., regulation and competition, in member state *i* in year *t*, as well as on a vector of demand and cost controls ($\mathbf{Z}_{i(t-1)}$). Note that $\mathbf{Z}_{i(t-1)}$ also contains a measure of the average broadband price level, *price_bb*, that explicitly controls for the competitive outcome in first generation broadband markets which allows estimating the direct supply-side effect of regulation and competition. The additive error term ε_{it} is assumed to be i.i.d and θ_i represents country-specific effects. Equation (1) includes lagged values of all exogenous variables in order to fully employ the availability of our panel dataset.[17]

Any adoption process is inherently dynamic and thus it is crucial to separate out adequately the technological diffusion effects from explanatory variables. The vast majority of the related empirical literature finds that (ICT) adoption processes are best described through S-shaped (logistic or Gompertz) functional curves which represent different versions of an exponential growth model which ultimately converges to some saturation level.[18] But, even in fibre-leading European countries the NGA adoption processes is still in its early phase and far from being close to respective inflection points.[19] Therefore, NGA adoption can be approximated by a simpler exponential growth model in equation (1) which relates NGA adoption (in logs), $ln(FTTx\_hh_{it})$, to a linear time trend, *t*.[20]

Equation (2) represents a dynamic extension of the baseline specification in equation (1) where the lagged dependent variable, $ln(FTTx\_hh_{i(t-1)})$, is included as a right-hand side variable (instead of the linear time trend, *t*). The coefficient α_1 measures the importance of network effects which give rise to an endogenous adoption process if $0 < \alpha_1 < 1$. $1 - \alpha_1$ measures the constant "speed of diffusion", λ, that comes from a Gompertz model of adoption (Kiiski and Pohjola, 2002, pp. 299-300). λ is expressed as the percentage of the gap between the long-run (desired or target) stock of NGA subscribers and

17 With an insufficient number of observations one would run the risk of over fitting the data. Also, assuming that adoption decisions at a particular point in time do not depend on contemporaneous but on last period´s conditions makes good sense as consumer´s adoption process will typically be – although to a much lesser extent than investment decisions of firms (Briglauer et al. 2013) – related to some non-negligible consumer inertia related to technology adjustment and switching costs.

18 For recent and ICT related diffusion studies see e.g. Czernich et al. (2011), Grajek and Kretschmer (2009) or Lee et al. (2011).

19 For recent evidence see Briglauer and Gugler (2012) or Samanta et al. (2012). In particular, note that one can infer from Figure A.1 that almost all EU27 states are far from the adoption target defined in the EC´s Digital Agenda ("50% or more of European households subscribe to internet connections above 100 Mbps").

20 Also, a log transformation helps to stabilize the series of our dependent variable. This represents a positive side effect in view of potential non-stationarity problems which cannot be tested formally given that our panel dataset is unbalanced and neither the number of time periods ($T \leq 8$) nor the number of cross-sectional units ($n \leq 27$) tend to infinity ("Im-Pesaran-Shin" unit-root test is designed for unbalanced panels but requires at least 10 observations per panel).

subscribers in the previous period that is closed each period (Andres et al., 2010; Kiiski and Pohjola, 2002; Grajek and Röller, 2012).[21] Again, the additive error term μ_{it} is assumed to be i.i.d:

$$(2) \qquad \begin{aligned} \ln(Fttx\_hh_{it}) &= \alpha_0 + \beta_1 reg\_bb_{i(t-1)} + \beta_2 fms_{i(t-1)} + \beta_3 fms^2{}_{i(t-1)} + \beta_4 bb\_lines\_hh_{i(t-1)} \\ &+ \gamma' \mathbf{Z}_{i(t-1)} + \theta_i + \alpha_1 \ln(Fttx\_hh_{i(t-1)}) + \mu_{it} \end{aligned}$$

Estimating the reduced form in equations (1) and (2) enables comparative static analysis which appears to be of prime importance for policy makers and in view of our policy-oriented research questions.[22]

6.2 Identification

The desire to measure causation and to avoid endogeneity in spite of reliance on non-experimental data is the key concern in empirical economics (Cameron and Trivedi, 2005, p. 715; Wooldridge, 2002, p. 421). We argue, first of all, that the main source of endogeneity in the form of reverse causality is effectively eliminated by the reduced form approach in equations (1) and (2): As we assess the impact of demand and supply-side determinants related to first generation broadband markets on second generation NGA markets, one can hardly imagine that current NGA adoption influences, for instance, previous regulation on broadband markets which was implemented by NRAs typically many years ago. Accordingly, reverse causality that might otherwise lead to endogeneity should represent no problem. Second, by lagging the explanatory variables, NGA adoption is related to pre-determined values of the independent variables. In order to reinforce these arguments, we also perform standard Granger causality tests. Third, we control for potential endogeneity due to unobserved and time-invariant heterogeneity by including fixed effects (θ_i) at the country level.

7 Empirical results[23]

Table 1 shows the main results using fixed effects ("FE") regressions to estimate our baseline specification (equation (1)). Regression (1) reports FE estimates for the model specification which contains all demand and cost controls ("Full"). The F-test (F_θ) following regression (1) shows that country level FE are significant, implying that pooled OLS would produce inconsistent estimates if the FE are correlated with the independent variables. Regression (1) reports t-statistics assuming that the errors in equation (1) are i.i.d, which might induce misleading inference as well (Cameron and Trivedi, 2005, pp. 711-712). Therefore, one has to control for both serial correlation and any arbitrary form of heteroscedasticity by calculating robust standard errors. For short panels ($T \leq 8$ in our case) this

[21] Let $Fttx\_hh_{it}^{*}$ denote the desired long-run stock of NGA subscribers, then the Gompertz model of diffusion specifies the rate of change as $(\partial Fttx\_hh_{it} / \partial t)(1/Fttx\_hh_{it}) = \lambda(\ln(Fttx\_hh_{it}^{*} - Fttx\_hh_{i(t-1)})$.

[22] For the sake of clarity we drop the cross-sectional index in the remainder of the paper.

[23] STATA 12.1 is used to estimate the regressions.

strategy is preferred over modelling a specific error correlation structure (Cameron and Trivedi, 2005, p. 725). Regression (2) contains FE estimates for the full model based on robust standard errors ("rob"). Note, however, that robust standard errors still assume that there is no contemporaneous correlation across the panel units. Typically, spatial dependence is unlikely to exist at the country level with short time series. Yet, Pesaran´s test of cross sectional independence does not provide unambiguous evidence (the statistic is -1.721 with a p-value of 0.0852 for regression (3)). Regression (5) therefore reports "Driscoll-Kraay" standard errors ("DK") which are assumed to be heteroskedastic, autocorrelated up to some lag and possibly correlated between the panels (Driscoll and Kraay, 1998; Hoechle, 2007).

In regressions (3) to (5) we eliminated all except the significant demand controls ($int\_user\_pc_{(t-1)}$, $edu_{(t-1)}$) and the least insignificant cost controls ($wage_{(t-1)}$, $urban_{(t-1)}$).[24] As it can be seen, the basic structure of the coefficients for the main variables remains effectively unchanged throughout regressions (1) to (5) which reassures us that those estimates are largely robust to alternative selections of control variables. The demand controls $int\_user\_pc_{(t-1)}$ and $edu_{(t-1)}$ are statistically significant with expected signs in all regressions in Table 1 and appear to best capture ICT affinity and e-literacy, respectively, as essential pre-conditions for the usage of high-speed broadband services.

The cost controls $wage_{(t-1)}$ and $urban_{(t-1)}$ are not only insignificant but the variable $urban_{(t-1)}$ also has unexpected sign in regressions (1) and (2). Whereas insignificant cost estimates appear to be primarily due to country FE (low within variation),[25] the unexpected sign of $urban_{(t-1)}$ might be attributed to two opposing effects: First, in densely populated areas, NGA deployment can serve more customers at the same time, so reducing the costs for a single fibre connection (economies of density). Second, however, total digging costs are much higher in urban areas where construction activities become more labour intensive. We therefore included the interaction term $urban*wage_{(t-1)}$ in regressions (3) to (5) to capture this relationship. Indeed, $urban_{(t-1)}$ then shows the expected sign and its impact on NGA adoption decreases with increases in the wage level, $wage_{(t-1)}$, in regressions (3) to (5).

With respect to period effects, we find that the linear time trend, t, is significant in regressions (3) and (5). With a constant annual growth rate of 0.5324 (= [exp(0.4268) – 1]) in regression (3), the number of homes connected would increase from its average value (0.05147) to the Digital Agenda´s target value (0.5) in about 5.4 years. Note, however, that this represents the most optimistic case, since constant exponential growth is unlikely to continue in later phases of the adoption process. We also estimated regression (3) as two-way FE by including year dummies instead of the linear time trend.

[24] Whereas $urban_{(t-1)}$ stands for demographic cost factors, $wage_{(t-1)}$ stands for construction costs. $wage_{(t-1)}$ is preferred over $labcost\_ict_{(t-1)}$, since only the former has expected (meaningful) sign.

[25] A second-stage regression using the estimated FE of regression (3) as the dependent variable shows that the variation in FE can be explained to a large extent by (highly) time-invariant demand and cost controls which are excluded from regression (3); results are available upon request from the author.

However, the year dummies are jointly insignificant (*F*-statistic is 0.92; not reported in Table 1) and hence inclusion would result in less efficient estimates.

Overall, we refer to regressions (3) to (5) as final regressions ("Final") as these are the most efficient specifications. When comparing regression (3) with regression (5) one finds that imposing "Driscoll-Kraay" standard errors substantially increases significance levels. But, as the estimator is based on an asymptotic theory, we have to consider the results with caution in view of our short panel structure.

(Table 1 about here)

Table 2 first represents in regression (6) the estimation results of model "Final_FE_rob", which we consider as our most appropriate specification (= regression (3) in Table 1). Regression (7) shows that coefficient estimates are virtually unchanged if we normalize our dependent variable with respect to total population ("pop") instead of total number of households. The first difference ("FD") specification in regression (8) also eliminates time-invariant heterogeneity but entails a substantial loss in efficiency. FD still shows similar estimates except for the coefficient of our regulation variable, $reg\_bb_{(t-1)}$, which has expected sign but is less well identified. Regression (9) reports the results of the random effects (RE) specification. Although RE coefficients show a similar structure and a similar coefficient estimate for the variable $reg\_bb_{(t-1)}$, the FE specifications are clearly preferred in view of our observational dataset.[26]

Finally, regression (10) contains the estimation results of the specification which includes the lagged dependent variable, $ln(Fttx\_hh_{(t-1)})$, as an additional regressor (equation (2)). Estimating regression (10) by means of an ordinary FE (within or LSDV) estimator would yield inconsistent and biased results, since the lagged dependent variable and the error terms would be correlated (Nickell, 1981). Bruno (2005a,b) developed a bias-corrected LSDV estimator ("LSDVC") for unbalanced panel data.[27] Again, the structure of the LSDVC estimation results in regression (10) is similar to the previous regressions and most coefficients of the main variables of interest are significant with expected signs.

[26] Conceptually, our analysis focuses on the EU27 member states which represent a particular set of rather homogenous countries and cannot be considered as a random sample drawn from the population of all countries. Empirically, a heteroskedastic- and cluster-robust Hausman test strongly rejects the RE model (in regression (6) the Sargan-Hansen test statistic is 71.025, not reported in Table 2), saying that RE estimates will be inconsistent.

[27] A weakness of GMM estimators is that their properties only hold for a large number of cross-sectional units ($n \leq 27$ in our case). Monte Carlo evidence supports the LSDVC estimator which proves to be (much) more efficient than various instrumental variable type estimators when n is small (Kiviet, 1995). However, LSDVC is not applicable in the presence of endogenous regressors (Bruno, 2005b). In view of the arguments in section 6.2, we are confident that there is no endogeneity problem as we control for unobserved heterogeneity and also reverse causality appears to be unlikely with respect to our empirical specification. To prove the latter, we also perform standard Granger causality tests (Granger, 1969). The results, which are reported in Table A.3 in the Appendix, indicate that there is no bidirectional causality.

Apparently, the coefficient of the lagged dependent variable, $ln(Fttx\_hh_{(t-1)})$, is highly significant and substantial (α_1 = 0.7056) in regression (10) which informs us about the relevance of network effects underlying the adoption of NGA services. A 10% increase in the number of NGA connections per household in the previous period leads to an increase of about 7.1% in the number of current NGA connections. Although a high value of α_1 might be either due to true state dependency or correlation with unobserved heterogeneity (θ_i), a causal mechanism via the last period is very likely because of the high potential of network effects for adoption of new ICT services as outlined in section 4.4. The speed of diffusion (λ = 1 - 0.7056) suggests that it will take around 6.5 years to close 90% of the gap between the average number of NGA connections per household (0.05147) and the Digital Agenda´s target value (0.5). Also, note that λ is significantly greater than zero which confirms that migration to NGA services is subject to some non-negligible switching costs on side of the consumers.

Regarding the main variables of interest, one first finds a significant and non-linear relationship with respect to our inter-platform competition variable, $fms_{(t-1)}$ and $fms^2_{(t-1)}$, for all FE regressions (including LSDVC). The maximum of the non-linear relationship informs us about the optimal competitive market conditions for NGA adoption. For instance, one can infer from the corresponding coefficient estimate in regression (3) in Table 1 (= regression (6) in Table 2) that a share of ~19.5% of fixed landlines is optimal. The grand mean of $fms_{(t-1)}$ is ~26.88% and thus above this optimal value which means that the escape competition effect still dominates the Schumpeterian effect and fixed-to-mobile substitution exerted a positive impact on NGA adoption in the past. However, increasing competition from mobile networks brought the average value of this variable close to its optimum during the analysis period with $\overline{fms}_{(2004)}$ = 0.3317 and $\overline{fms}_{(2011)}$ = 0.2314.[28]

The coefficient of the variable $bb\_lines\_hh_{(t-1)}$ is significantly negative in all FE regressions (excluding LSDVC) from which we infer that there is a substantial replacement effect with reference to the first generation broadband infrastructure. As the latter includes both DSL and cable connections, we also tested whether there is a differential effect with respect to these forms of intra-platform competition by including an additional interaction term, $bb\_lines*cable_{(t-1)}$, in regression (4) in Table 1. As the corresponding coefficient is insignificant (as well as the coefficient of the main effect, $cable_{(t-1)}$), we conclude that there is no differential impact and the replacement effect equally comes from both types of fixed broadband infrastructure. This result appears to be reasonable in view of rather similar quality and price characteristics of intra-modal coax and copper/DSL broadband retail services.

Finally, we find a coefficient of the regulatory variable, $reg\_bb_{(t-1)}$, which is estimated in the quite narrow range of -2.3210 to -2.3608 for the final FE regressions and significantly negative throughout all estimations (except for the FD specification). This strongly supports our hypothesis outlined in

[28] It is interesting to contrast this result with the corresponding finding in Briglauer et al. (2013) who measure mobile competition in a different way (based on survey data for the years from 2005 to 2010) but also find that competition stemming from mobile networks increased but is well below its optimum value on average.

section 4.1 that more intense regulation has a negative impact on adoption of NGA services once we control for the price effect. The average estimate of the coefficient of $reg\_bb_{(t-1)}$ (~ -2.35) implies that an increase of regulatory intensity by 10 percentage points leads to a decrease of the NGA adoption by 20.95% ([=*exp*(-2.35*0.1)-1]*100). Evaluated at the grand mean, which represents the average EU27 member state, this implies an average decrease from 0.05147 to ~0.0407 NGA lines per household.

The average broadband price variable, $price\_bb_{(t-1)}$, is only marginally significant. As it has negative sign throughout, we infer that the price variable mainly stands proxy for NGA prices or for a general broadband price level as presumed. Indeed, if we drop $price\_bb_{(t-1)}$ from the regressions, the coefficient of $reg\_bb_{(t-1)}$ increases throughout in absolute terms (e.g., from ~-2.352 to ~-2.435 in regression (3)). However, since this increase is not significant, we infer that the negative direct impact of regulation on supply-side investment activities dominates the price effect on the demand side.

(Table 2 about here)

8 Summary and final remarks

This work identifies the effects of sector-specific ex ante regulation and infrastructure competition on the adoption of NGA services in Europe using a recent panel dataset of EU27 countries. As opposed to previous related literature, the econometric specification explicitly addresses the endogeneity problem mainly by relating NGA adoption to regulation and competition on preceding broadband markets.

The results, first, indicate that NGA adoption is negatively influenced by the extent and effectiveness of wholesale broadband access regulation that is imposed on the incumbent's first generation DSL infrastructure. Also, it should be pointed out that the impact of regulation is quite substantial. Accordingly, the ambitious goals of the EC´s Digital Agenda seem to be at odds with the sector-specific EU regulatory framework, which intends to expand strict cost-based access regulation to the emerging NGA infrastructure and corresponding NGA wholesale access services. Realizing the targets of the EC to reach 50% adoption with 100 Mbit/s high-speed internet connections until 2020, becomes much more unlikely if the prime importance is attached to high cost FTTH/B deployment scenarios (Briglauer and Gugler, 2012). Secondly, competition stemming from mobile networks impacts NGA adoption in a non-linear way as expected. With respect to the time-frame of our analysis, the positive impact of the escape competition effect dominates the Schumpeterian effect. Thirdly, we also found evidence of a significant replacement effect underlying the first generation broadband infrastructure, which might get even reinforced in the future in view of the potential of new DSL and coax technologies. Finally, our dynamic specification suggests that substantial network effects give rise to an endogenous NGA adoption process. As this process exhibits a high growth potential, the target of the EC appears to be still feasible time-wise, if one refers to a broad NGA definition and if NGA adoption is not endangered by shocks on the demand or supply side or, most notably, by wrong policy incentives.

It should be noted once again that the intention of the paper is neither to identify demand *or* supply related to NGA adoption and deployment, respectively, nor to analyze the dynamics of the involved adjustment processes; instead, the paper focused on the marginal effects of the main policy variables of interest by means of comparative static analysis. In view of the dynamic interaction of supply and demand, a proverbial chicken-and-egg situation appears to arise: It is not clear a priori, whether there have to be demand for new, attractive services in advance in order to enforce deployment of new communications infrastructure or if those services and applications will automatically evolve after the necessary infrastructure has already been put in place. Internet history indicates that the development of content and applications usually followed infrastructure deployment, e.g. there would be none of the web 2.0 services and social platforms available in a world with narrowband dial-up internet infrastructure. This view suggests that the ambitious goals of the EC´s Digital Agenda can be reached best, if NGA deployment is primarily supply-side driven; either by means of deregulatory approaches or via optimal competitive market conditions as indicated by our results and the vast majority of the broadband related literature. In addition, state aid intervention targeted to supply NGA deployment in non-profitable areas or to stimulate the speed of technology diffusion might be considered as effective and complementary policy instruments.

Table 1: Estimation results for the adoption model (dependent variable: $ln(Fttx\_hh_{it})$)

Regression (nr.)	(1) **Full_FE**	(2) **Full_FE_ rob**	(3) **Final_FE_ rob**	(4) **Final_FE_ rob_i**	(5) **Final_FE_ rob_DK**
$reg\_bb_{(t\text{-}1)}$	-1.8962** (-2.29)	-1.8962** (-2.33)	-2.3515*** (-2.99)	-2.3166** (-2.74)	-2.3515*** (-4.08)
$price\_bb_{(t\text{-}1)}$	-0.0258* (-1.92)	-0.0258* (-1.81)	-0.0270 (-1.58)	-0.0266 (-1.50)	-0.0270*** (-5.60)
$fms_{(t\text{-}1)}$	57.1295*** (3.60)	57.1295* (1.97)	45.0935** (2.27)	47.0737** (2.19)	45.0935*** (4.84)
$fms^2_{(t\text{-}1)}$	-136.263*** (-4.67)	-136.2630** (-2.39)	-115.5386** (-2.75)	-115.9163** (-2.66)	-115.54*** (-5.62)
$bb\_lines\_hh_{(t\text{-}1)}$	-6.6056*** (-2.92)	-6.6056*** (-2.94)	-4.9070* (-1.99)	-5.2888** (-2.22)	-4.9070*** (-4.12)
$int\_user\_pc_{(t\text{-}1)}$	8.1608** (2.00)	8.1608** (2.18)	5.1423** (2.14)	4.4192 (1.46)	5.1423*** (3.43)
$edu_{(t\text{-}1)}$	0.2315*** (2.98)	0.2315*** (3.15)	0.1577** (2.22)	0.1516* (2.00)	0.1577* (1.94)
$telco\_rev\_hh_{(t\text{-}1)}$	51.5279 (0.11)	51.5279 (0.08)			
$i\_iday_{(t\text{-}1)}$	-0.8730 (-0.17)	-0.8730 (-0.13)			
$i\_iugm_{(t\text{-}1)}$	-1.2253 (-0.41)	-1.2253 (-0.41)			
$gdp\_pc\_ppp_{(t\text{-}1)}$	0.0000 (0.46)	0.0000 (0.65)			
$hh\_dens_{(t\text{-}1)}$	2.4201 (0.60)	2.4201 (0.63)			
$labcost\_ict_{(t\text{-}1)}$	0.0276 (1.09)	0.0276 (0.90)			
$labcost_{(t\text{-}1)}$	-0.0071 (-0.41)	-0.0071 (-0.45)			
$wage_{(t\text{-}1)}$	-0.1330 (-0.66)	-0.1330 (-0.78)	0.9914 (1.40)	0.8436 (1.24)	0.9914* (1.82)
$urban_{(t\text{-}1)}$	-0.3195 (-1.19)	-0.3195 (-0.97)	0.1094 (0.31)	0.1736 (0.46)	0.1094 (0.44)

$mdw_{(t-1)}$	-0.0026	-0.0026			
	(-0.73)	(-0.72)			
t	0.3753	0.3753	0.4268*	0.4886*	0.4268***
	(1.40)	(1.17)	(1.71)	(1.76)	(4.78)
$urban*wage_{(t-1)}$			-0.0161	-0.0145	-0.0161**
			(-1.57)	(-1.49)	(-2.28)
$bb\_lines*cable_{(t-1)}$				-10.3659	
				(-0.78)	
$cable\_entr_{(t-1)}$				10.5496	
				(0.87)	
Constant	-12.2036	-12.2036	-25.0350	-29.5231	-25.0350*
	(-0.52)	(-0.45)	(-1.07)	(-1.18)	(-1.78)
Adjusted R^2	0.634	0.705	0.731	0.723	
R^2_o	0.0202	0.0202	0.0226	0.0350	
R^2_w	0.7406	0.7406	0.7482	0.7439	0.7482
F	16.6541	176.1775	26.5819	26.4628	1685.8718
F_θ	7.8923				
RMSE	0.9353	0.8406	0.8530	0.8563	
Obs	149	149	175	174	175

Regressions (1) to (5) include country-specific fixed effects (FE) which are not reported. *t*-statistics in parentheses are based on panel robust standard errors in regressions (2) to (5). Indeed, a Wooldridge test for autocorrelation indicates that there is first-order autocorrelation in the data. Likewise, a Wald test for groupwise heteroskedasticity clearly rejects the null hypothesis of a constant variance. Regression (5) employs "Driscoll-Kraay" standard errors ("DK"), where the autocorrelation structure has a lag length of *m(T)=floor*[4(*T*/100)^(2/9)] which turned out to be robust to alternative lag specifications. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

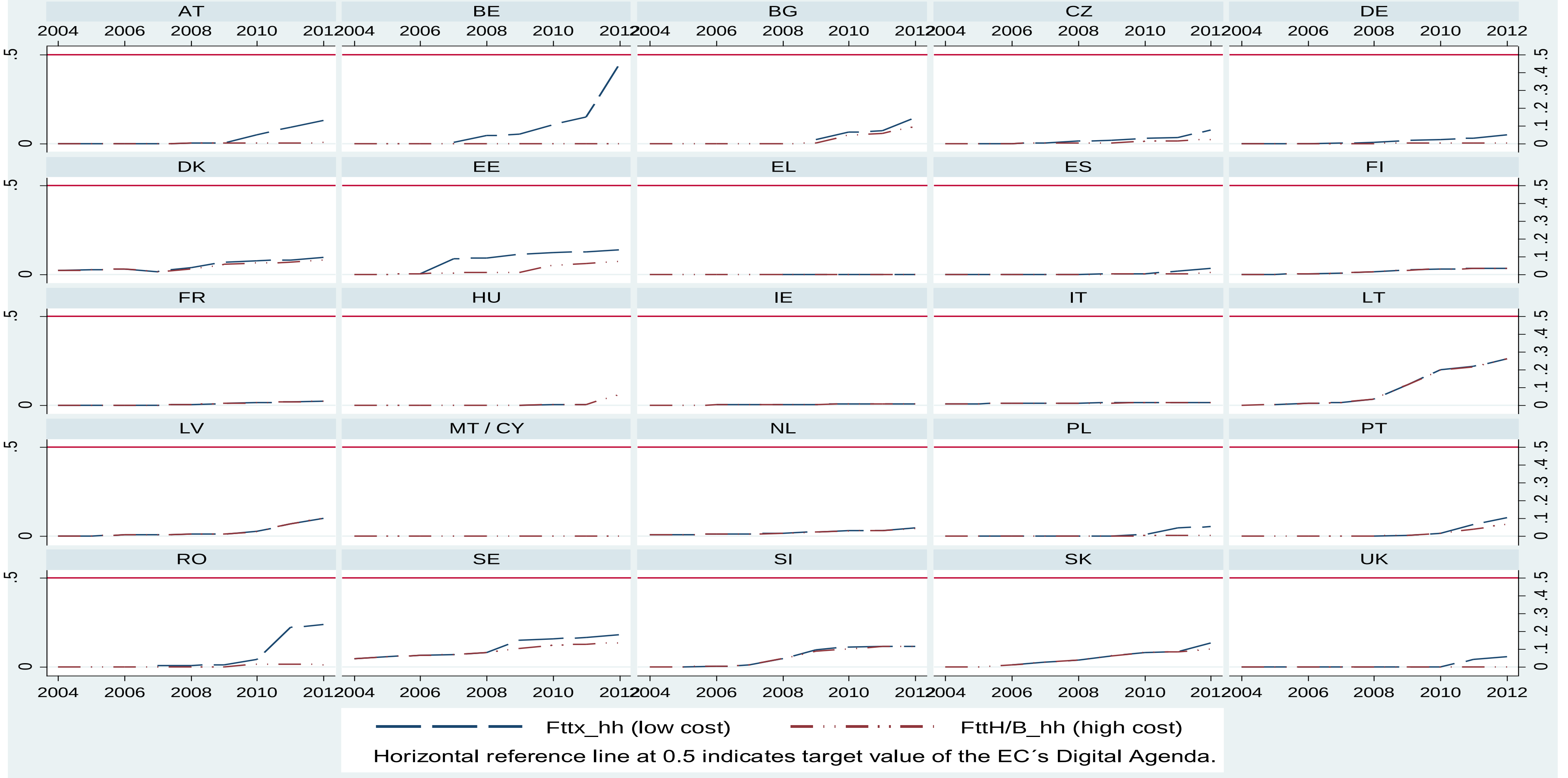
Table 2: Estimation results for different specifications of the "Final" adoption model

Regression nr.	(6) **Final_FE_ rob**	(7) **Final_FE_ rob_pop**	(8) **Final_FD_ rob**	(9) **RE_Final_ rob**	(10) **LSDVC_Final**
$lnFttx\_hh_{(t-1)}$					0.7056^{***} (8.82)
$reg\_bb_{(t-1)}$	-2.3515^{***} (-2.99)	-2.3608^{***} (-2.99)	-0.6629 (-1.52)	-2.6598^{***} (-2.68)	-2.1195^{***} (-2.83)
$price\_bb_{(t-1)}$	-0.0270 (-1.58)	-0.0274 (-1.60)	-0.0214^{*} (-1.81)	-0.0277 (-1.49)	-0.0243^{***} (-2.70)
$fms_{(t-1)}$	45.0935^{**} (2.27)	44.9592^{**} (2.26)	27.3118 (1.50)	29.8178 (1.33)	18.0557^{*} (1.90)
$fms^2_{(t-1)}$	-115.5386^{**} (-2.75)	-115.5528^{**} (-2.73)	-63.7250^{*} (-1.74)	-71.9990 (-1.55)	-39.9050^{**} (-2.08)
$bb\_lines\_hh_{(t-1)}$	-4.9070^{*} (-1.99)	-4.9498^{*} (-2.01)	-4.1934^{**} (-2.12)	-3.0706 (-1.34)	-1.0464 (-0.72)
$int\_user\_pc_{(t-1)}$	5.1423^{**} (2.14)	5.0215^{**} (2.11)	4.3991^{**} (2.60)	6.5363^{***} (3.04)	2.0246 (0.91)
$edu_{(t-1)}$	0.1577^{**} (2.22)	0.1581^{**} (2.22)		0.0292 (0.94)	0.0338 (0.50)
$urban_{(t-1)}$	0.1094 (0.31)	0.1164 (0.33)		-0.0131 (-0.25)	-0.0107 (-0.04)
$wage_{(t-1)}$	0.9914 (1.40)	1.0140 (1.43)		-0.0284 (-0.15)	-0.0699 (-0.11)
$urban*wage_{(t-1)}$	-0.0161 (-1.57)	-0.0164 (-1.60)		0.0008 (0.35)	0.0002 (0.02)
t	0.4268^{*} (1.71)	0.4325^{*} (1.73)		0.3365 (1.54)	
Constant	-25.0350 (-1.07)	-26.3051 (-1.12)	0.5745^{***} (3.25)	-12.1558^{**} (-2.34)	
Adjusted R^2	0.731	0.732	0.089		
R^2_o	0.0226	0.0173		0.4763	
R^2_w	0.7482	0.7493		0.7127	
F	26.5819	26.7343	2.2558		
RMSE	0.8530	0.8532	0.8385	0.9821	
Obs	175	175	149	175	162

t-statistics in parentheses are based on panel robust standard errors in regressions (6) to (9). LSDVC standard errors in regression (10) are bootstrapped based on 100 iterations with bias correction initialized by Arellano and Bond estimator for estimates up to order O(1/T) . * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Annex

Figure A.1: NGA household adoption levels for FTTx and FTTH/B technologies in the EU27



Source: FTTH Council Europe. Fttx and FttH/B household adoption levels are (essentially) zero in MT (CY).

As data for Luxembourg is available only for 2009 onwards and due to its exceptionally high FTTx adoption level, Luxemborug is not included in Figure A.1.

Table A.1: Variable description and sources

Variable (expected sign)	Description	Source*
	Dependent variable(s)	
FTTx connections per household, *Fttx_hh*, *(Fttx_pop)*	Number of households connected by FTTx technologies normalised to a country´s total number of households, (normalised to total population)	©FTTH Council Europe[(a)]
	Main explanatory variables	
Extent of broadband access regulation, *reg_bb (-)*	Share of regulated lines (local loop unbundling, bitstream, resale) to total retail broadband lines (minus cable entrant lines)	EU Progress Report[(b)]
Broadband price, *price_bb (?/-)*	Average monthly cost of capped/uncapped residential fixed broadband for 1Mbps-10Mbps in Euro excluding VAT. Tariffs are a weighted average of representative stand-alone products of incumbent and entrant operators whose accumulative subscribers are over 90% of each country´s total broadband market	©Quantum-Web Limited[(c)]
Broadband lines, *bb_lines_hh (-)*	Number of total retail broadband lines (DSL and coax) as a share of total number of households ("homes connected")	EU Progress Report ©EUROMONITOR (households)
Fixed-to-mobile substitution, *fms (+(levels) - (squared term))*	Share of total number of fixed landlines to total number of fixed lines and mobile subscribers. *Mobile-cellular telephone subscriptions* include the number of postpaid subscriptions, and the number of active prepaid accounts (that have been used during the last three months). It excludes subscriptions via data cards or USB modems. *Fixed-landlines* refer to the number of active lines connecting subscribers' terminal equipment to the PSTN	ITU[(d)]
Cable lines, *cable (?)*	Number of total retail broadband cable lines run by entrants as a share of total retail broadband lines	EU Progress Report
	Control variables	
Education, *edu (+)*	Percentage of adult population (25-64 years old) that has completed at least upper secondary education	EUROSTAT[(e)]
GDP per capita, *gdp_pc_ppp (+)*	GDP per capita and PPP adjusted in current US$	World Bank[(f)]
Average revenue, *telco_rev_hh (+)*	Total telecommunications revenues in mn US$ per household with constant 2011 prices and fixed 2011 exchange rates	©EUROMONITOR[(g)]
Heavy internet use, *i_iugm (+)*	Share of population using bandwidth intense internet services (games, films, music...)	EUROSTAT / COCOM
Heavy internet users, *i_iday (+)*	Share of population using internet services every or almost every day	EUROSTAT / COCOM[(h)]

Table A.1: Variable description and sources (cont`d)

Variable (expected sign)	Description	Source*
Household density, *hh_dens (+)*	Average number of household members, expressed as a share of a country´s population to its total number of households	©EUROMONITOR (households) EUROSTAT (population)
Internet users, *int_user_pc (+)*	Internet users per capita	©EUROMONITOR
ICT labor cost index, *labcost_ICT (-)*	Annual ICT labor cost index normalised to 100 in 2008	EUROSTAT
Labor cost index, *labcost (-)*	Annual labor cost index normalised to 100 in 2005	© EIU[(i)]
Multiple dwellings, *mdw (+)*	Annual Building permits - number of two and more dwellings normalized to 100 in 2005	EUROSTAT
Wage per hour, *wage (-)*	Wage per hour manufacturing in US$ with constant 2011 prices, fixed 2011 exchange rates	© EIU
Urban population, *urban (+)*	Urban population as a percentage of total population	©EIU

* Note that some sources are commercially available only (©) while others are publicly available.

(a) FTTH Council Europe is a non-profit industry organisation, whose aim is to enforce deployment of fibre optic technology in Europe. Data are collected by IDATE (www.idate.org) through desk research, direct contacts with FTTx players, information exchange with FTTH Council Europe members and from IDATE partners. Data from June 2005 to June 2011 and December 2011 (= 2012) are available to its members at: http://www.ftthcouncil.eu/resources?category_id=6. Data for Bulgaria and Luxembourg are available only for 2009 onwards. There are no data for Malta and the number of subscribers for Cyprus is de facto time-constant and essentially null (with one rise from 100 to 120 FTTx lines). (b) The EU "Progress Report on the Single European Electronic Communications Market" for data from 2004 to 2011 is available at: http://ec.europa.eu/information_society/policy/ecomm/library/communications_reports/index_en.htm. There are missing values for Bulgaria and Romania for the years from 2004 to 2006. (c) Data are based on a quarterly monitoring service that harvests over 2000 fixed broadband tariffs across 100 countries. A few missing values for the variable *price_bb* had to be linearly interpolated. (d) ITU World Telecommunication/ICT Indicators Database is available at: http://www.itu.int/ITU-D/ict/statistics/ (e) Data is available at: http://epp.eurostat.ec.europa.eu/portal/page/portal/information_society/data/database. Data for *i_iugm* is available only for the years from 2004 to 2010 and there are a few missing values for the variables *i_iugm* and *iday* which had to be linearly interpolated. (f) World Bank's "World Development Indicators" available at: http://data.worldbank.org. (g) Euromonitor International database is available at: http://www.euromonitor.com/. The number of households in 2012 was set equal to the number in 2011. (h) Data collected by EC services, through NRA´s, for the Communications Committee (COCOM). (i) Economist Intelligence Unit country database is available at: https://eiu.bvdep.com/frame.html.

Table A.2: Summary statistics

Variable	Variation	Mean	Std. Dev.	Min	Max	Obs*
Fttx_hh	overall	0.0514702	0.1047494	3.77E-06	0.8574688	N = 191
	between		0.1182229	0.0003915	0.6090008	n = 26
	within		0.053404	-0.2063078	0.3651736	T = 7.35
Fttx_pop	overall	0.0212465	0.0406438	1.52E-06	0.3171702	N = 191
	between		0.0442877	0.000135	0.2252358	n = 26
	within		0.0218185	-0.0724796	0.1573267	T = 7.35
reg_bb	overall	0.2435517	0.2218102	0	0.9947678	N = 210
	between		0.1927122	0.0007791	0.7037244	n = 27
	within		0.1177948	-0.1030858	0.9905862	T = 7.77
price_bb	overall	29.76357	15.75987	5.26	99.89	N = 226
	between		6.735677	14.76	42.9425	n = 27
	within		14.45547	-1.438927	87.1408	T = 8.37
fms	overall	0.2688139	0.0746535	0.1076148	0.437505	N = 216
	between		0.0652995	0.1467276	0.3925803	n = 27
	within		0.0380519	0.1677713	0.4134962	T = 8
edu	overall	68.26574	13.96395	26	86.1	N = 216
	between		14.02081	28.7375	84.2125	n = 27
	within		2.192978	61.44074	74.80324	T = 8
gdp_pc_ppp	overall	29405.69	13476.8	8730.804	89055.8	N = 216
	between		13352.13	12284.78	80394.91	n = 27
	within		3024.771	13967.07	38066.58	T = 8
telco_rev_hh	overall	0.0023742	0.0010328	0.0004868	0.0046744	N = 216
	between		0.001019	0.0007302	0.0041021	n = 27
	within		0.0002493	0.0015673	0.0031638	T = 8
i_iday	overall	0.4021399	0.1808903	0.036	0.8039	N = 216
	between		0.1431649	0.1363003	0.6732108	n = 27
	within		0.1135449	0.1730875	0.6173487	T = 8
i_iugm	overall	0.2317125	0.0926456	0.0479	0.5073836	N = 189
	between		0.0711529	0.1299117	0.4058385	n = 27
	within		0.0606799	-0.029026	0.4552803	T = 7
bb_lines_hh	overall	0.4201162	0.2130044	0.0069897	0.8752053	N = 210
	between		0.134138	0.1841686	0.6984428	n = 27
	within		0.1673422	-0.0182887	0.7883213	T = 7.77

Table A.2: Summary statistics (cont`d)

Variable	Variation	Mean	Std. Dev.	Min	Max	Obs*		
cable	overall	0.0898561	0.0843489	0	0.377342	N	=	209
	between		0.0734082	0	0.2756474	n	=	27
	within		0.0423109	-0.1400215	0.2205538	T	=	7.75
hh_dens	overall	2.507075	0.2827785	1.999367	3.204768	N	=	243
	between		0.2841833	2.017063	3.002026	n	=	27
	within		0.0432815	2.404574	2.801087	T	=	9
int_user_pc	overall	0.6064277	0.1844711	0.1500006	0.9325179	N	=	216
	between		0.1598241	0.3020208	0.8754859	n	=	27
	within		0.0965272	0.3604697	0.8102632	T	=	8
labcost_ICT	overall	96.27037	13.70907	47.7	165.1	N	=	216
	between		5.409287	82.0625	105.7625	n	=	27
	within		12.63451	57.79537	160.2454	T	=	8
labcost	overall	112.0291	21.62619	81.4439	226.7329	N	=	213
	between		13.68069	100.4715	153.58	n	=	27
	within		17	45.38391	193.4653	T	=	7.89
mdw	overall	89.98745	46.11853	9.96	344.11	N	=	216
	between		28.42763	43.29	184.8463	n	=	27
	within		36.6756	-15.2588	249.2512	T	=	8
wage	overall	16.00741	11.13623	1.6	51.4	N	=	216
	between		1.13E+01	1.975	49.75	n	=	27
	within		0.7132549	13.35741	18.54491	T	=	8
urban	overall	72.08326	11.79625	48.6801	97.4358	N	=	216
	between		11.97782	49.31314	97.34392	n	=	27
	within		0.5954232	69.90087	74.22487	T	=	8
t	overall	5	2.587318	1	9	N	=	243
	between		0	5	5	n	=	27
	within		2.587318	1	9	T	=	9

* *n* denotes the number of individual units and *N* denotes the total number of individual-time observations. Uppercase *T* denotes the number of time periods (annual observations).

Table A.3: Standard (direct) Granger causality tests with LSDVC*

Regression nr. Dependent var. Independent var.	(A.1) ***$logFttx\_hh_{(t)}$***	(A.2) ***$reg\_bb_{(t-1)}$***	(A.3) ***$price\_bb_{(t-1)}$***	(A.4) ***$fms_{(t-1)}$***
$logFttx\_hh_{(t-1)}$	0.7033*** (9.08)			
$logFttx\_hh_{(t-2)}$		**-0.0226** **(-1.23)**	**0.0572** **(0.05)**	**0.0002** **(0.12)**
$logFttx\_hh_{(t-3)}$		**0.0077** **(0.53)**	**-0.1574** **(-0.17)**	**0.0009** **(0.67)**
$reg\_bb_{(t-2)}$	**-1.2063*** **(-1.94)**	0.2256* (1.80)	-6.2001 (-0.73)	-0.0007 (-0.05)
$price\_bb_{(t-2)}$	**-0.0085** **(-0.79)**	0.0004 (0.20)	0.4371*** (3.51)	0.0000 (0.19)
$fms_{(t-2)}$	**7.2783** **(0.70)**	1.2461 (0.66)	220.0209* (1.82)	1.0701*** (10.41)
$fms^2_{(t-2)}$	**-10.8759** **(-0.58)**	-2.6688 (-0.70)	-399.1218* (-1.66)	-0.6293*** (-3.18)
Granger causality tests with *p*-values of $\chi 2$-tests of joint significance of respective coefficients displayed in bold in regressions (A.1) to (A.4):				
Prob > $\chi 2$ (lag1)	0.0365**	0.4637	0.9853	0.6585
Obs	150	113	112	113
Prob > $\chi 2$ (lag 2)	0.0780*	0.3005	0.6417	0.5080
Obs	124	112	112	112

* Since Granger causality tests require inclusion of lagged dependent variables, we had to use the LSDVC specification (regression (10) in Table 2). In order to test for reverse causality all variables with significant coefficients in regression (10) are considered. LSDVC calculates a bias-corrected LSDV estimator where the dependent variable is lagged once on the left hand side. Therefore, we include only one lag of the respective dependent variable in regressions (A.1) to (A.4). In regression (A.1) causation is established, since our main regulatory and competition variables are jointly significant in line with our baseline specification. The lower part of Table A.3 shows the *p*-values for the Granger $\chi 2$-test once for inclusion of one lag and once for inclusion of two lags of the independent variables (corresponding coefficient estimates and *t*-statistics for the latter case are not reported in Table A.3). For regressions (A.2) to (A.4) the Granger causality $\chi 2$-statistics are highly insignificant, suggesting that there is, as expected, no reverse causality.

LSDVC standard errors in regression (A.1) to (A.4) are bootstrapped based on 100 iterations with bias correction initialized by Arellano and Bond estimator for estimates up to order O(1/T). * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

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